Research needs for

Greenhouse Gas Inventory Methods

by Amber Kerr
Energy and Resources Group, UC Berkeley

and Margaret Torn
Earth Sciences Division, Lawrence Berkeley National Laboratory and Energy and Resources Group, UC Berkeley

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Draft California Greenhouse Gas Inventory (millions of metric tonnes of CO2 equivalent) — By IPCC Category

onday, November 19, 2007	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	200
n	0.23	0.21	0.19	0.14	0.15	0.17	0.15	0.15	0.14	0.14	0.14	0.14	0.13	0.13	0.1
ring : Stone, Clay, Glass & Cement : Lime > Lime production > CO2	0.234	0.208	0.190	0.144	0.151	0.170	0.155	0.149	0.138	0.135	0.138	0.136	0.133	0.131	0.1
y	2.34	1.93	1.81	1.52	1.68	1.63	1.27	1.23	1.41	1.22	1.38	1.19	1.24	1.26	1.3
ring : Chemicals & Allied Products > Fuel consumption - LPG > CO2	0.052	0.059	0.060	0.058	0.067	0.068	0.071	0.072	0.075	0.078	0.071	0.066	0.072	0.072	0.07
hemicals & Allied Products > Fuel consumption - Natural Gas > CO2	0.862	0.769	0.591	0.475	0.549	0.540	0.568	0.480	0.650	0.513	0.628	0.540	0.556	0.564	0.5
& Allied Products > Fuel consumption - Petroleum feedstocks > CO2	0.894	0.567	0.604	0.604	0.627	0.530	0.337	0.378	0.398	0.356	0.410	0.363	0.374	0.397	0.4
uction	0.53	0.54	0.55	0.38	0.44	0.49	0.30	0.30	0.28	0.27	0.27	0.22	0.23	0.23	0.2
emicals & Allied Products : Nitric Acid > Nitric acid production > N2O	0.535	0.538	0.555	0.385	0.438	0.486	0.296	0.296	0.285	0.274	0.267	0.217	0.235	0.228	0.2
ucts from Fuels and Solvent Use	2.29	1.92	2.03	2.04	1.90	1.78	1.58	1.63	1.92	2.18	1.85	1.64	1.78	1.56	1.3
	1.13	1.01	1.03	1.05	1.10	1.08	1.05	1.11	1.16	1.17	1.15	1.06	1.04	0.96	0.9
Not Specified Industrial > Fuel consumption - Lubricants > CO2	0.484	0.433	0.442	0.450	0.470	0.462	0.449	0.474	0.496	0.501	0.494	0.603	0.596	0.551	0.5
Not Specified Transportation > Fuel consumption - Lubricants > CO2	0.646	0.578	0.589	0.600	0.627	0.616	0.598	0.632	0.661	0.668	0.658	0.452	0.447	0.413	0.4
e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Not Specified Industrial > Fuel consumption - Waxes > CO2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0
ecify)	1.16	0.91	1.00	0.99	0.80	0.70	0.53	0.52	0.76	1.01	0.70	0.58	0.74	0.59	0.3
Not Specified Industrial > Fuel consumption - Asphalt > CO2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0
Not Specified Industrial > Fuel consumption - Naphtha > CO2	0.938	0.755	0.897	0.897	0.696	0.608	0.486	0.471	0.699	0.948	0.635	0.512	0.668	0.525	0.3
ed Industrial > Fuel consumption - Other Petroleum Products > CO2	0.219	0.151	0.099	0.094	0.105	0.097	0.049	0.053	0.065	0.061	0.065	0.069	0.073	0.069	0.0
try	0.59	0.59	0.59	0.74	0.82	1.02	1.12	1.29	1.43	1.43	1.23	0.86	0.83	0.81	0.8
ronic Equip. : Semiconductors & Related Products > Semiconductor manufacture > Halogenated gases (in CO2 Eq.)	0.592	0.592	0.592	0.735	0.817	1.021	1.123	1.287	1.430	1.428	1.229	0.862	0.825	0.806	0.8
Substitutes for Ozone Depleting	0.04	0.07	0.36	0.92	1.83	3.86	5.39	6.92	7.91	8.87	9.76	10.72	11.77	12.87	13.9
Specified > Use of [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.000	0.000	0.001	0.001	0.001	0.001	0.0
fied > Use of substitutes for ozone depleting substances > [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.052	1.191	1.350	1.502	1.665	1.878	2.1

If you cannot measure it,
you cannot improve it.

~ Lord Kelvin (William Thomson,
1st Baron Kelvin), 1824 - 1907

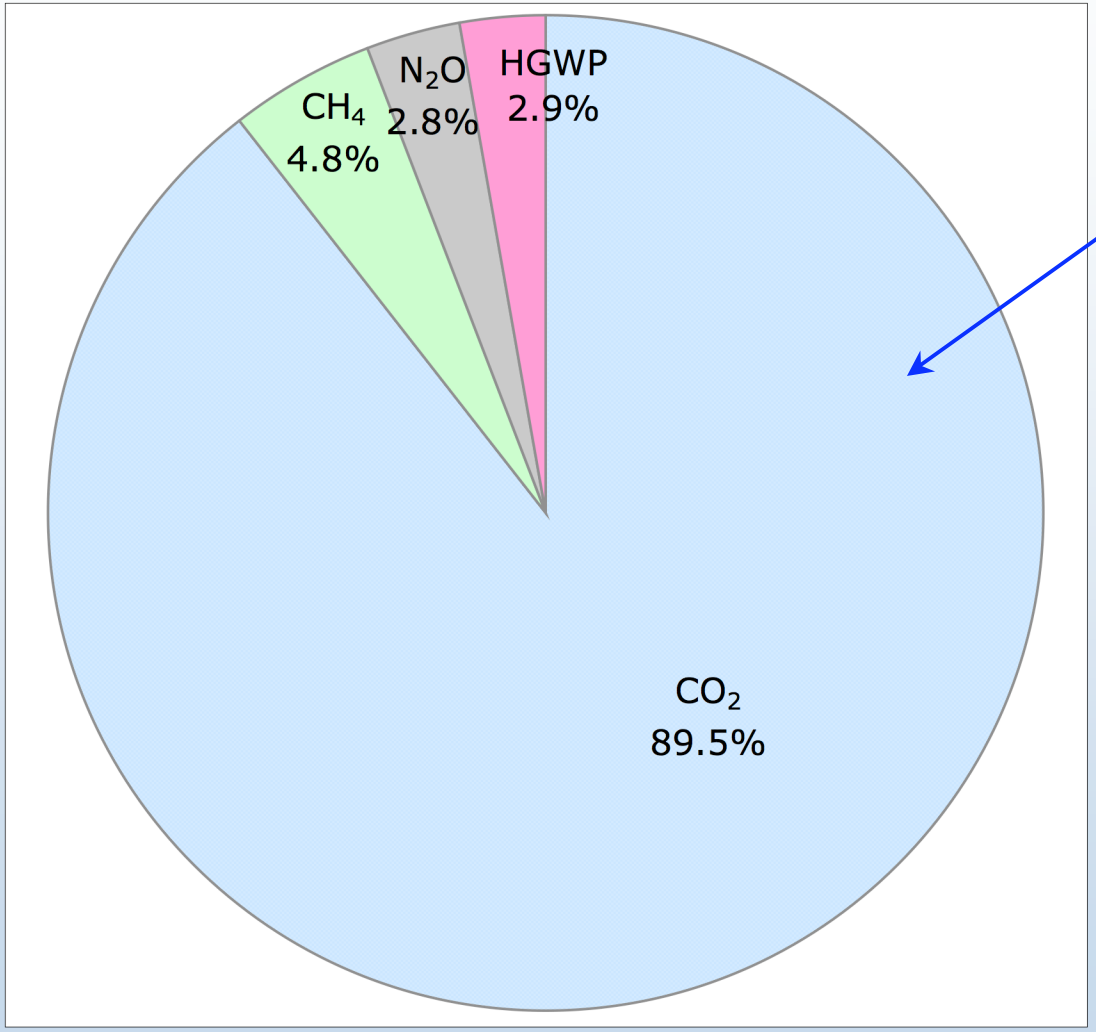
Outline

- Brief history of California's GHG inventory
- Facts and figures
- Uncertainty and how to reduce it
- Criteria for selecting research priorities
- **Our recommendations for research to improve California's GHG inventory**
- Items we chose not to recommend
- Summary and conclusions
- Most importantly: your feedback!

A brief history of California's GHG inventory

- The California Energy Commission compiled California's first GHG inventory in 1999, following IPCC guidelines.
- CEC continued to compile the inventory until 2006, when AB 32 (the Global Warming Solutions Act) became law.
- Since 2006, the California Air Resources Board has assumed responsibility for the inventory and for collecting "mandatory reporting" data.

California's 2004 GHG emissions *by gas*



Carbon dioxide is by far the largest component of the inventory.

CO_2 = carbon dioxide

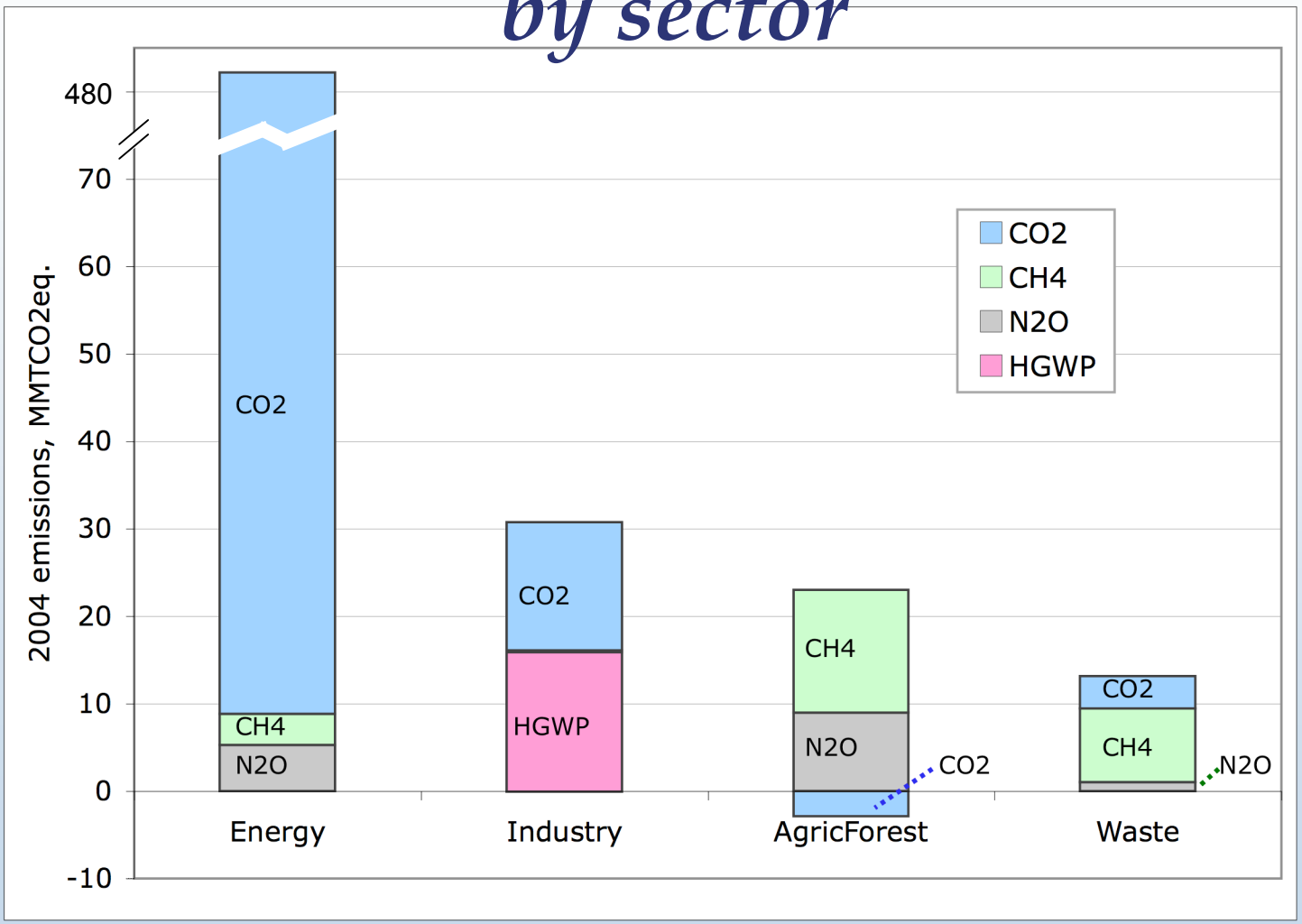
CH_4 = methane

N_2O = nitrous oxide

HGWP = high global warming potential gases

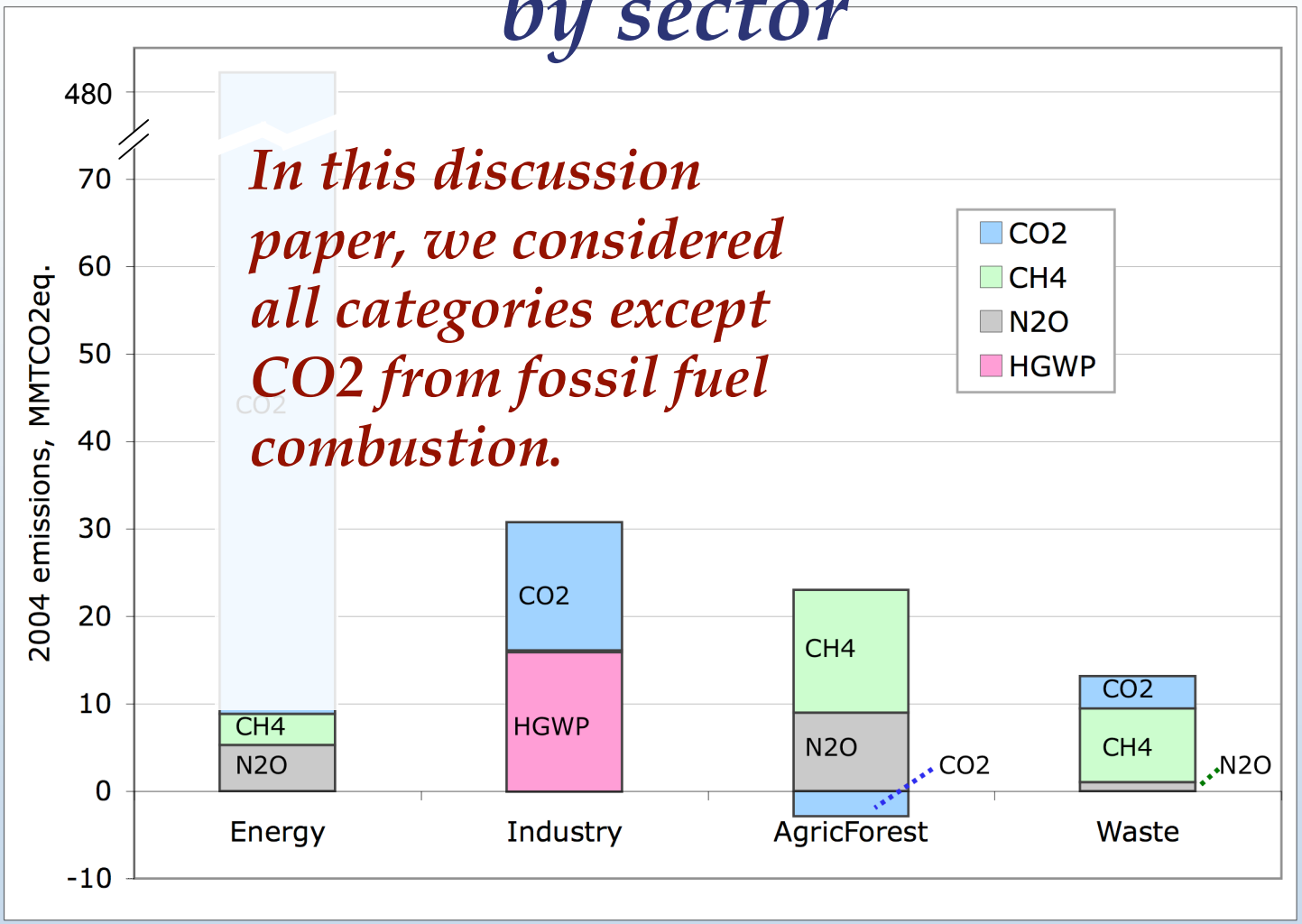
Data from ARB's inventory, completed 11/2007

California's 2004 GHG emissions *by sector*



Data from ARB's inventory, completed 11/2007

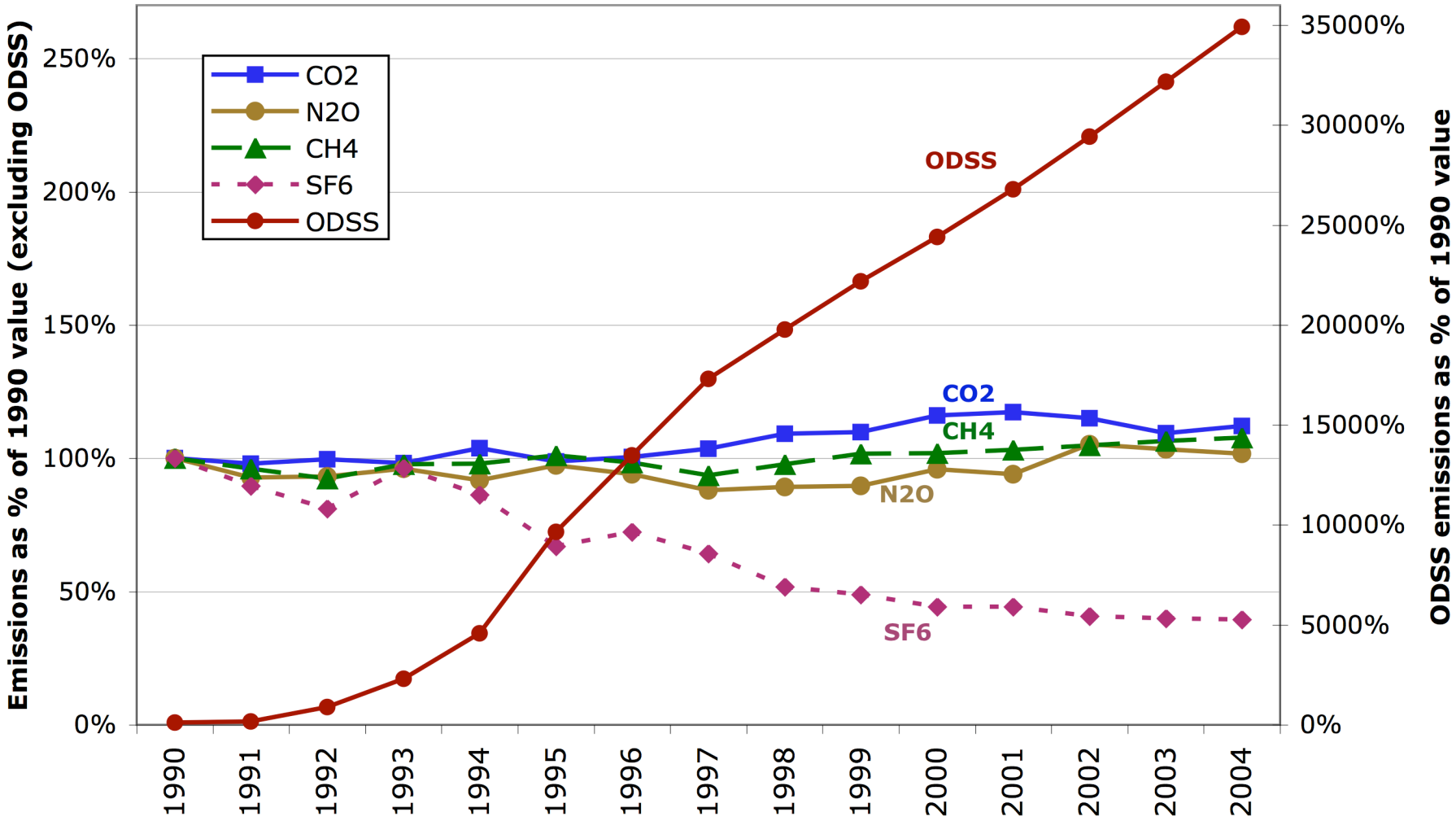
California's 2004 GHG emissions *by sector*



In this discussion paper, we considered all categories except CO2 from fossil fuel combustion.

Data from ARB's inventory, completed 11/2007

Trends in GHG emissions, 1990-2004



ODSS data from ARB's inventory (2007); other data from CEC's inventory (Bemis, 2006)

How do we measure GHG emissions?

- In most cases we must estimate them.
- Estimation methods include:
  - Emissions factor (EF) × activity data
  - Energy balance (how much energy was used?)
  - Process model (more sophisticated than EF)
  - Inverse modeling (tracing a plume to its source)
- Which approach is best? This depends upon the quality of our data, and how well we understand the processes involved.

Improving our estimates

To improve the inventory's accuracy, we can:

- Collect better activity data (acres of cropland, number of trucks).
- Develop more accurate emissions factors, perhaps specific to a region, system, or crop.
- Switch from an EF model to a process model (*if the process model produces better results*).
- Improve the representation of processes in a process model.
- Include new gases or sources that have previously been omitted.

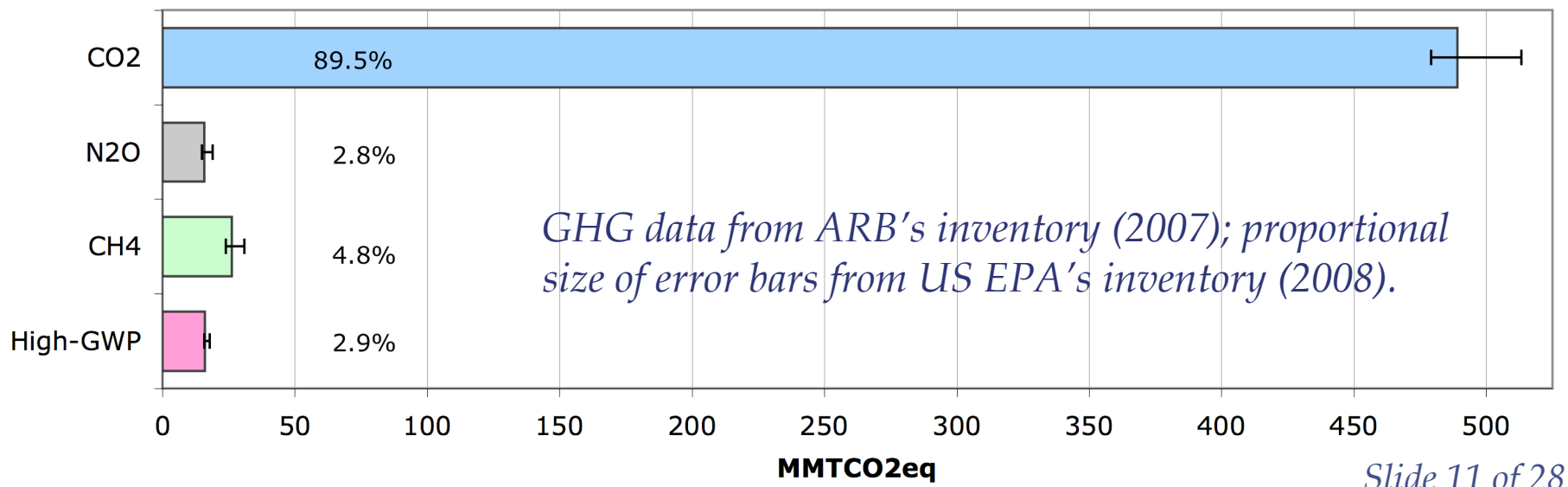
Uncertainty

- To improve the inventory's accuracy, we should focus research on the sectors that contribute most to its uncertainty.
- This does not necessarily mean the largest sectors; some sectors of small magnitude have very large uncertainty.
- In this context, there are different ways of defining and calculating uncertainty:
  - **Parameter uncertainty**
  - **Model uncertainty**

Parameter uncertainty

$$N_2O_{DIRECT} = ((F_{SN} + F_{AM} + F_{BN} + F_{CR}) \times EF_1) + (F_{OS} \times EF_2)$$

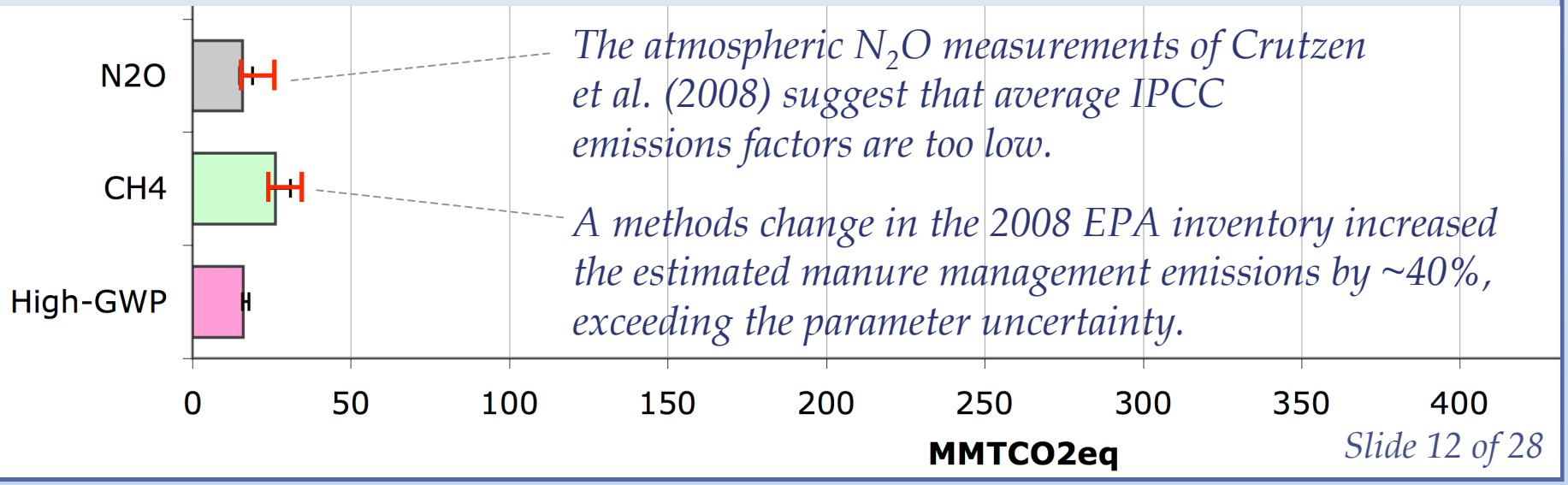
- Parameter uncertainty is the combined uncertainty in the input parameters, *assuming the underlying model structure is correct.*
- The US EPA inventory includes Monte Carlo estimates of parameter uncertainty (below).



GHG data from ARB's inventory (2007); proportional size of error bars from US EPA's inventory (2008).

Model uncertainty

- Model uncertainty is the difference between model predictions and actual values.
- Unlike parameter uncertainty, it requires comparison with another model and/or with empirical data.
- Often, model uncertainty overwhelms the uncertainty in the input data.

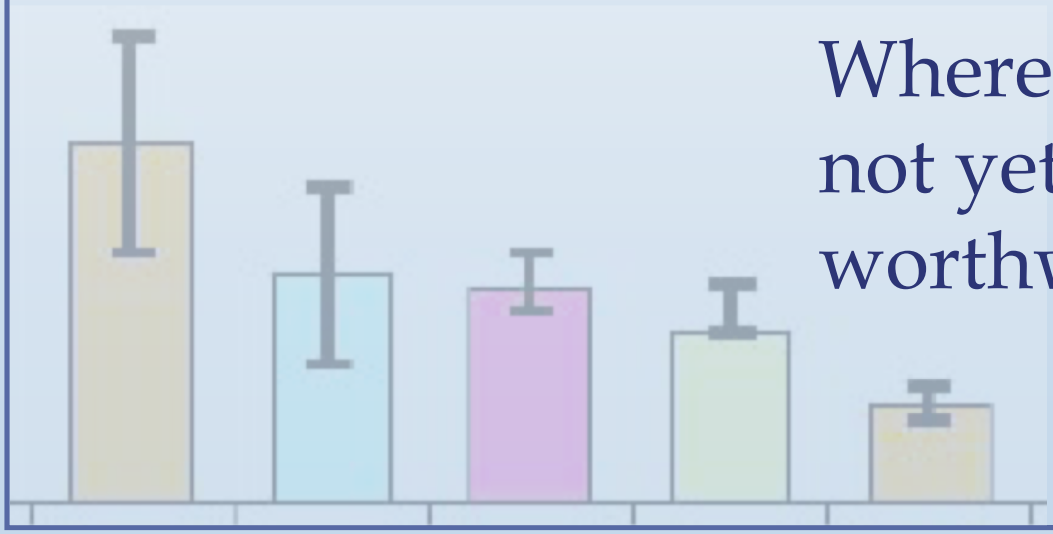


The atmospheric N_2O measurements of Crutzen et al. (2008) suggest that average IPCC emissions factors are too low.

A methods change in the 2008 EPA inventory increased the estimated manure management emissions by ~40%, exceeding the parameter uncertainty.

In greenhouse gas inventories, uncertainty is rarely quantified at all; most assessments of uncertainty are subjective.

We suggest that CEC-PIER rely wherever possible on *numerical estimates of uncertainty* when choosing research priorities.



Where these estimates do not yet exist, it may be worthwhile to create them.

Past and current PIER research
(a brief list)

Completed:

- Carbon in CA forests (Brown et al., 2004-07)
- Process modeling of agricultural soils (DNDC, by Li et al. 2004; DAYCENT, by De Gryze, Six et al., 2006)
- ...and of dairies (DNDC, by Salas et al., 2008)
- Atmospheric CO_2 monitoring (Fischer et al., 2005)

Ongoing:

- Atmospheric GHG monitoring (Fischer, Saber et al.)
- Methane from landfills (Bogner et al.)
- N_2O measurements from agricultural soils (TBD)

What are other agencies doing to improve GHG inventory methods?

US Environmental Protection Agency

- Developing nationally and regionally specific emissions factors
- Collecting empirical observations to assess inventory methods
- Implementing process models (e.g. DAYCENT)

California Air Resources Board

- Taking atmospheric measurements of GHGs (both well-mixed and point source)
- Monitoring criteria pollutants

(only a partial list!)

Identifying research priorities

- In recommending research priorities, we took into account
  - the magnitude of a category *(sector or gas)*
  - its absolute and proportional uncertainty
  - its potential for short- to medium-term improvement
- We also considered PIER criteria, including:
  - applicable to California specifically
  - generation of co-benefits
  - clear need for state support; likelihood of securing co-funding

Our list of research priorities

High Priority
1. CO_2 from agricultural soil; reconciliation with forestry methods
2. N_2O from agricultural soils (including indirect emissions)
3. High-GWP gases
4. Fugitive CH_4 emissions
5. CH_4 from landfills
Medium Priority
6. Ozone (precursor inventory)
7. Inverse methods

1. CO_2 from agricultural soil

- This sector is currently omitted from California's inventory, but the data exist to calculate it.
- Previous studies indicated that agricultural soil could be a net carbon source (Brown et al., 2004) or a net carbon sink (Li et al., 2004).

- Following the new IPCC guidelines, agricultural and forestry data sets should be reconciled.

2. N_2O from agricultural soil
(direct and indirect emissions)

- N_2O is emitted from agricultural soil through a series of intricate reactions.
- These reactions can take place where the N fertilizer was applied (*direct*), or in a remote location to which the fertilizer escaped (*indirect*).
- CA's current inventory uses an emissions factor approach for both emissions types. A process model may offer better accuracy; data would be needed to verify this.

N_2O emissions: direct and indirect

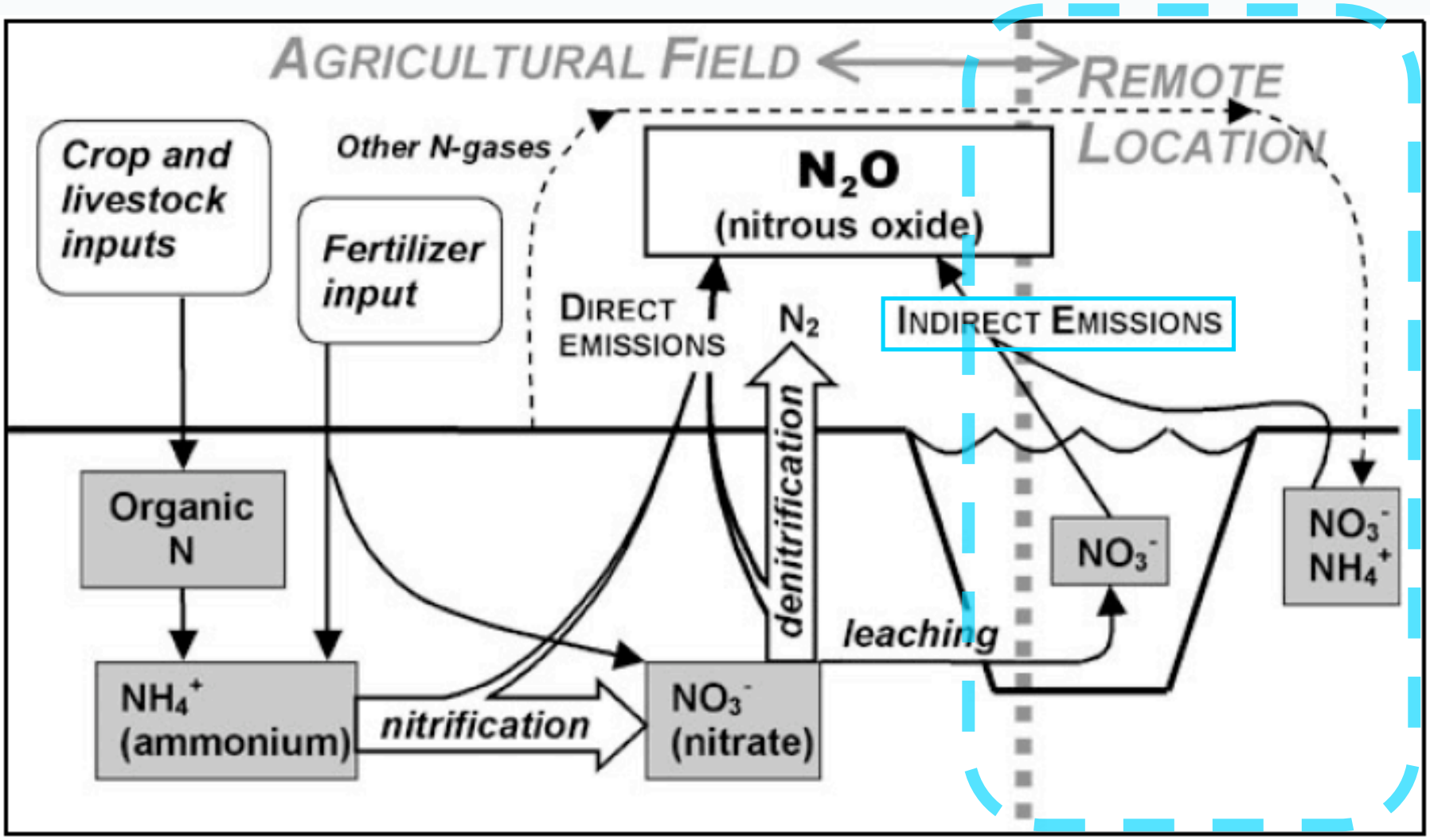
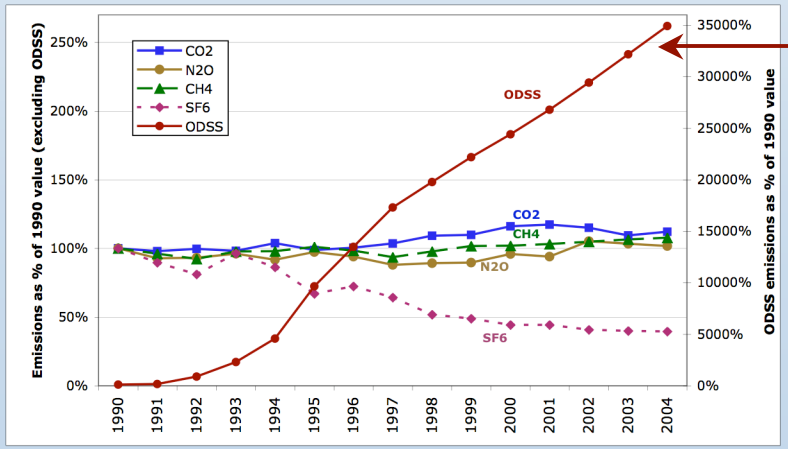


Figure 4.10 from Farrell et al. (2005), "Research Roadmap for Greenhouse Gas Inventory Methods."

3. High-GWP gases

- These diverse gases include the refrigerant HFC-134a and the insulator SF_6.
- Many have global warming potentials thousands of times greater than CO_2.
- Of concern is their rapid growth, and the potential for new unknown sources to arise.



The only gas species undergoing rapid increase in California's inventory

4. Fugitive CH_4 emissions

- Methane escapes from oil and gas drilling operations directly into the atmosphere.
- These fugitive emissions, though significant, are poorly monitored. CA's current inventory calculates fugitive emissions as a fraction of ARB's CEIDARS organic emissions database.

- This sector has been overlooked relative to others of the same size, and could be improved by the collection of California-specific data.

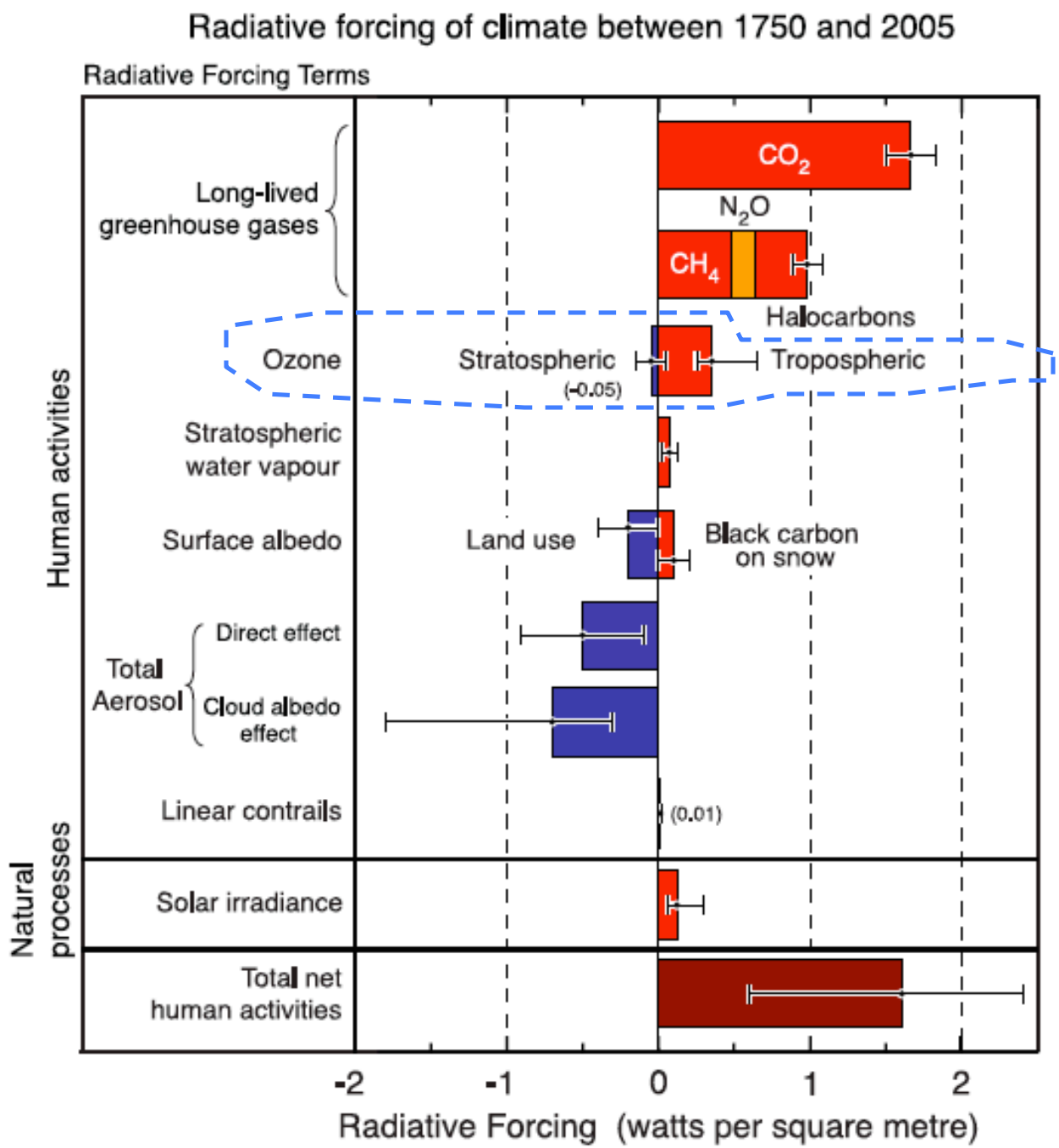
5. CH_4 from landfills

- The processes that produce (and consume) methane in landfills are complicated, and imperfectly characterized by CA's current methodology.
- Jean Bogner et al. (Landfills, Inc.) are currently conducting a PIER-funded study to improve theoretical models of landfill decay.

- Given the size and complexity of this sector, we expect more research will be needed.

6. Ozone precursors

- Ozone is not currently a mandatory part of any inventory; however, it likely will be in the future, as its radiative forcing is large.
- ARB tracks ozone precursor emissions by mass of gas, but there is no protocol to quantify their global warming potential.
- The estimation of ozone's global warming impact is a long-term goal on which CEC and ARB could collaborate.



The importance of tropo-spheric ozone

Figure 2 from FAQ 2.1, IPCC 4th Assessment Report, WG1, Chapter 2.

7. Inverse methods

- Measuring atmospheric concentrations of GHGs provides a valuable test of the accuracy of "bottom-up" methods.
- For this reason, we recommend that PIER continue funding inverse modeling work.

- Since ARB is working on similar projects, the potential for collaboration is great.

Low priority research topics

We choose not to recommend the following topics for PIER-funded research at this time:

- CH_4 and N_2O from wastewater (*very small magnitude*)
- N_2O from mobile sources (*small magnitude, work by ARB*)
- CH_4 and N_2O from manure management and enteric fermentation (*work by PIER*)

Again, note that we did not consider emissions from fossil fuel combustion.

Conclusions

- California's GHG inventory has been much improved since it began in 1999, but there are still large gaps to fill.
- PIER should choose research priorities according to a sector's magnitude, uncertainty, and potential for improvement.
- We recommend pursuing topics with a clear short-term payoff (e.g. CO_2 from agricultural soils) but not neglecting longer-term projects (indirect N_2O; ozone precursors).
- Opportunities for collaboration abound!

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Thank you

Your comments and questions are enthusiastically welcomed!

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(continued)

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